Lifetime Difference and CP Asymmetry in the $B_s \rightarrow J/\psi\phi$ decay

SUSY07

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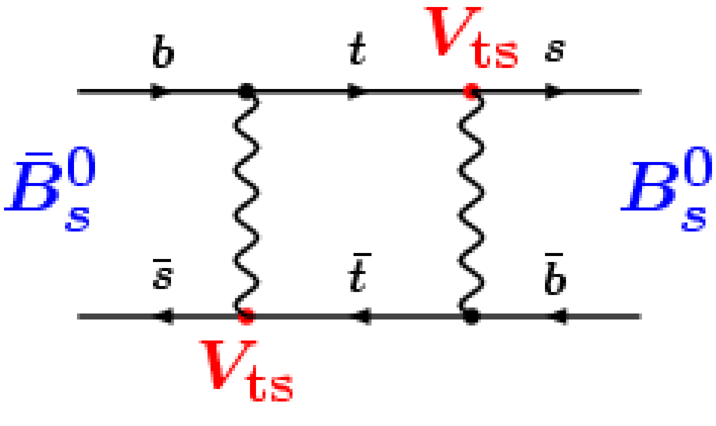
on behalf of the CDF collaboration

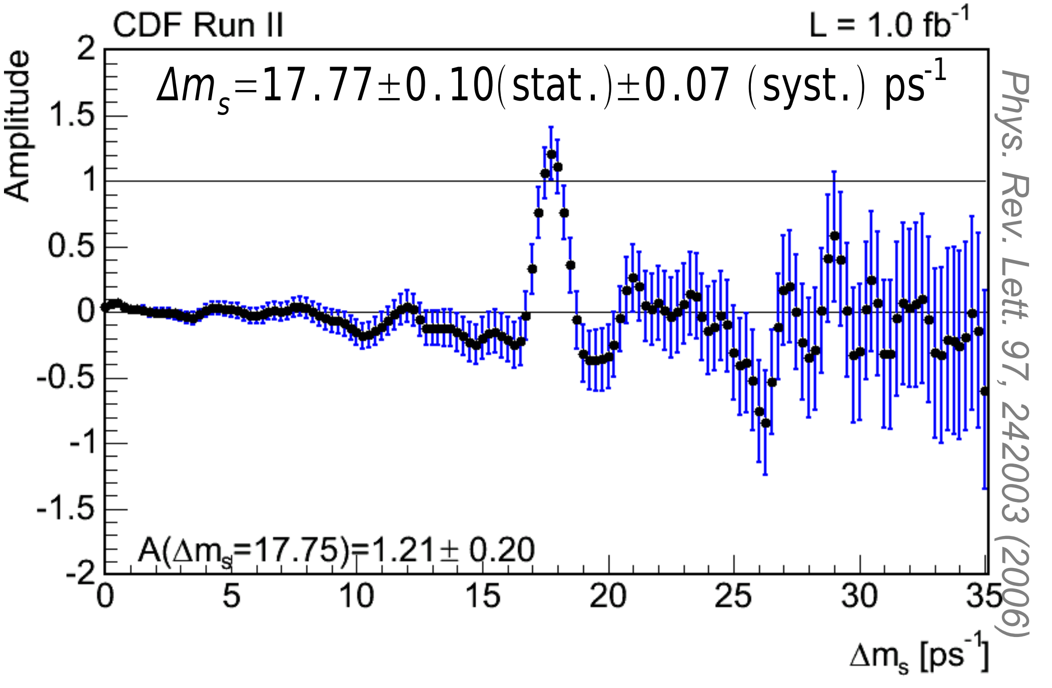
The B_s Meson System → Mass

Flavor eigenstates ≠ mass eigenstates

$$|B_{sL}\rangle = p|B_s\rangle + q|\bar{B}_s\rangle$$
$$|B_{sH}\rangle = p|B_s\rangle - q|\bar{B}_s\rangle$$

$\Delta m_s = m_H - m_L > 0$
⇒ flavor oscillation





The B_s Meson System → Lifetime

Flavor eigenstates ≠ mass eigenstates

$$\begin{aligned} |B_{sL}\rangle &= p\,|B_s\rangle + q\,|\bar{B}_s\rangle \\ |B_{sH}\rangle &= p\,|B_s\rangle - q\,|\bar{B}_s\rangle \end{aligned}$$

$$\Delta\Gamma_s = \Gamma_L - \Gamma_H$$

CDF: PRL 94, 122001 (2005)
D0: PRL 98, 121801 (2007)

$\Delta\Gamma_s$ large ⇒ sensitivity to mixing induced CP-violating phase ϕ_s without tagging

$$e^{i\phi_s} = \frac{V_{ts}V_{tb}^*}{V_{ts}^*V_{tb}}\frac{V_{cs}V_{cb}^*}{V_{cs}^*V_{cb}}$$

Standard model: $\Delta\Gamma_s \approx 0.1\ \text{ps}^{-1}$, $\phi_s \approx -0.02$

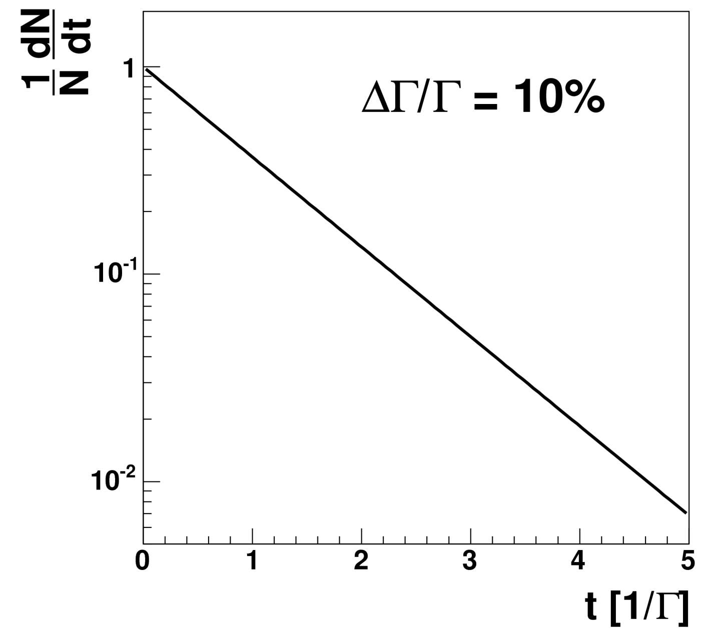
⇒ *large $|\phi_s|$ would indicate new physics!*

Lifetime Difference Measurement

- Measurement of lifetime distribution
- Fit of two exponentials

➔ Very difficult for low $\Delta\Gamma/\Gamma$

➢ *Need more information to separate two mass eigenstates*



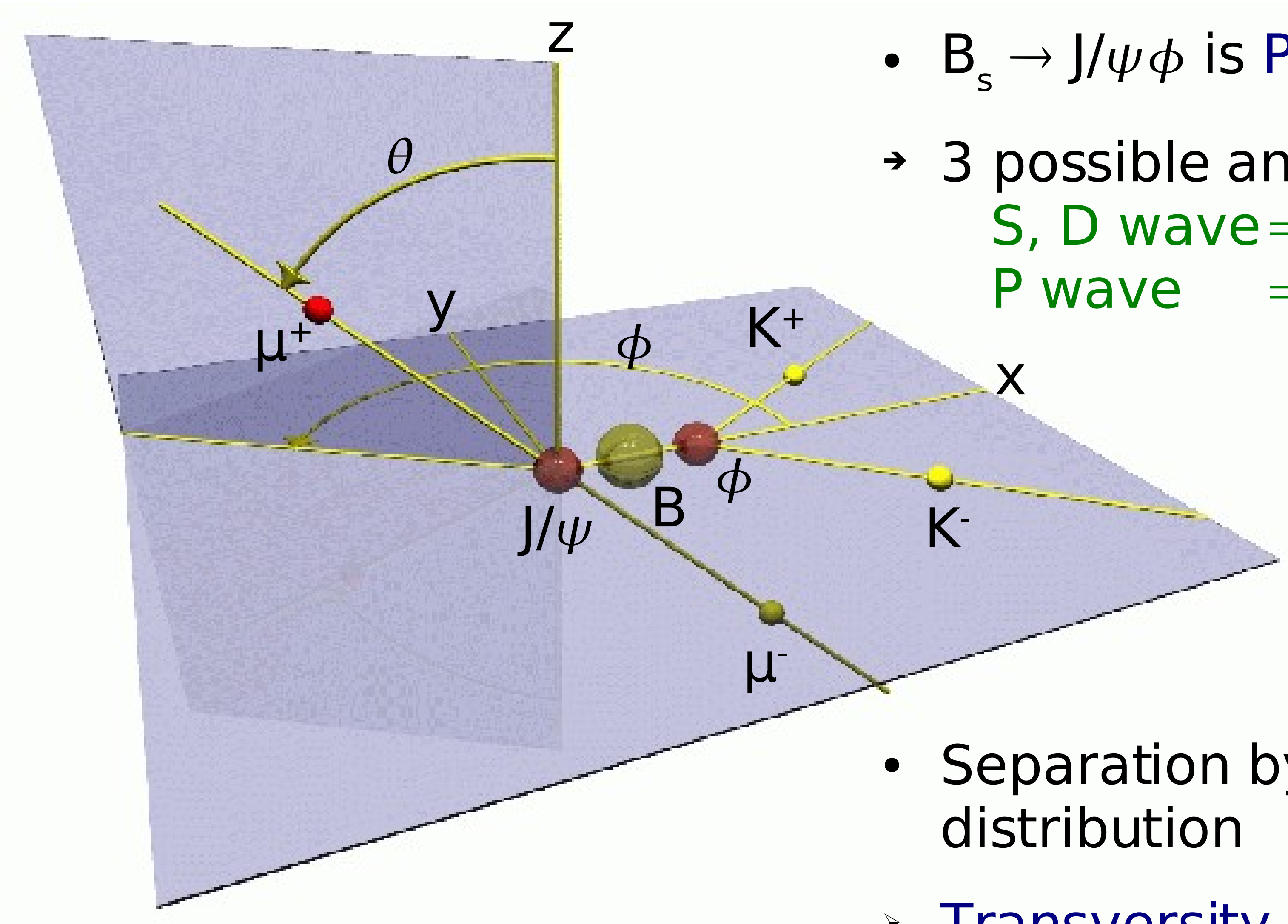
- In case of no CP violation (ϕ_s = 0):

  $|B_{sH}>$ = CP odd eigenstate

  $|B_{sL}>$ = CP even eigenstate

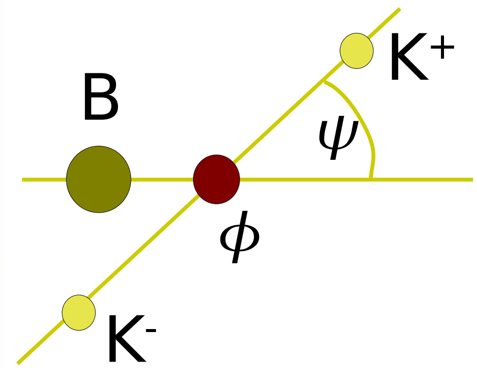
➔ Decay $B_s \to J/\psi\,\phi$ (composition of CP even and odd)

Angular Analysis



- $B_s \rightarrow J/\psi\phi$ is $P \rightarrow VV$ decay

➔ 3 possible angular momenta:
  S, D wave ⇒ CP even
  P wave ⇒ CP odd



- Separation by angular distribution

➢ Transversity angles $\theta, \ \phi, \ \psi$

$B_s \to J/\psi\phi$ Reconstruction with CDF II

Muon Chambers

- Muon ID

Central Drift Chamber

- Momentum
- Mass
- Angles

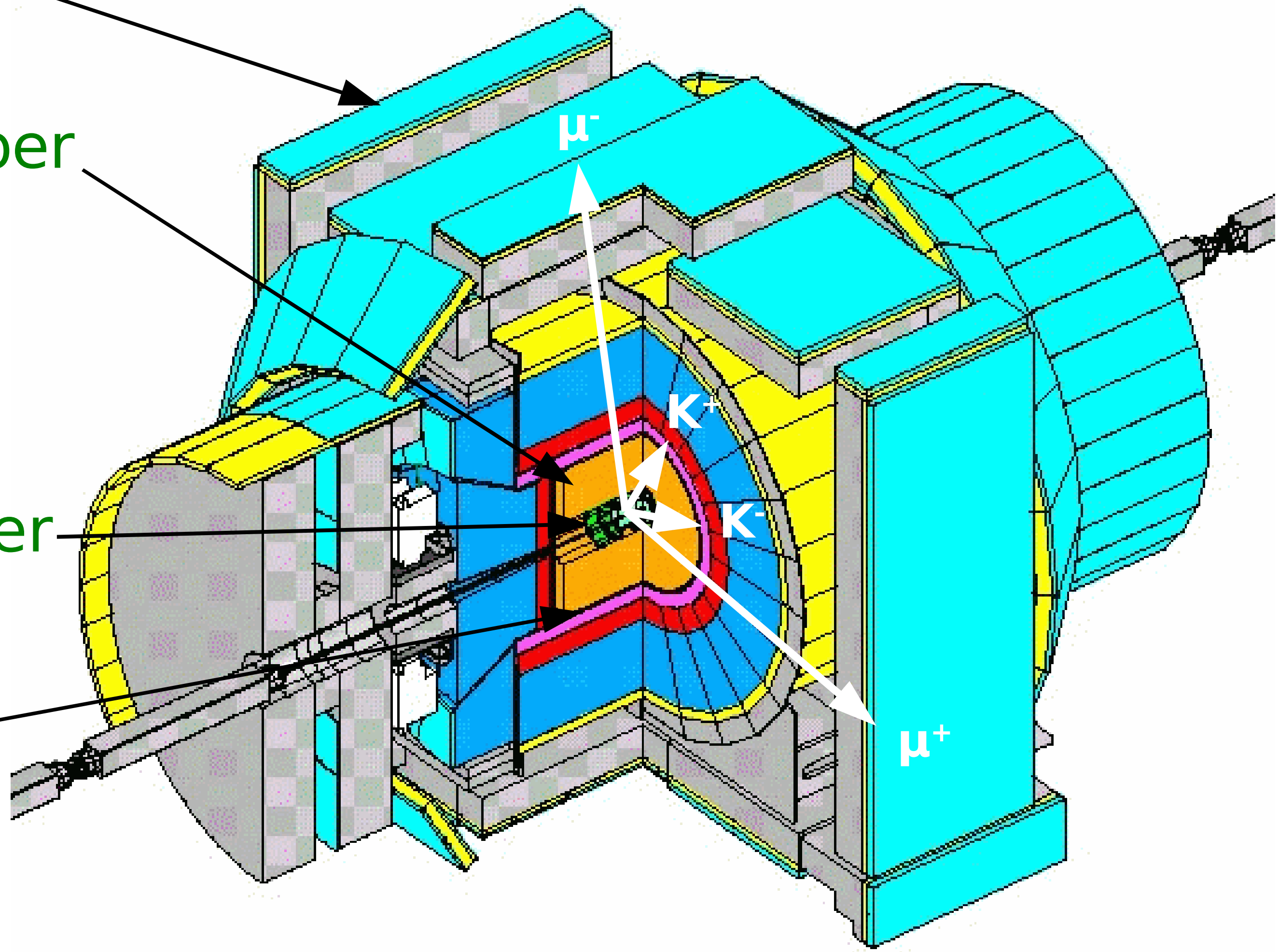
Silicon vertex tracker

- Lifetime

Time of flight

- PID

Dimuon trigger



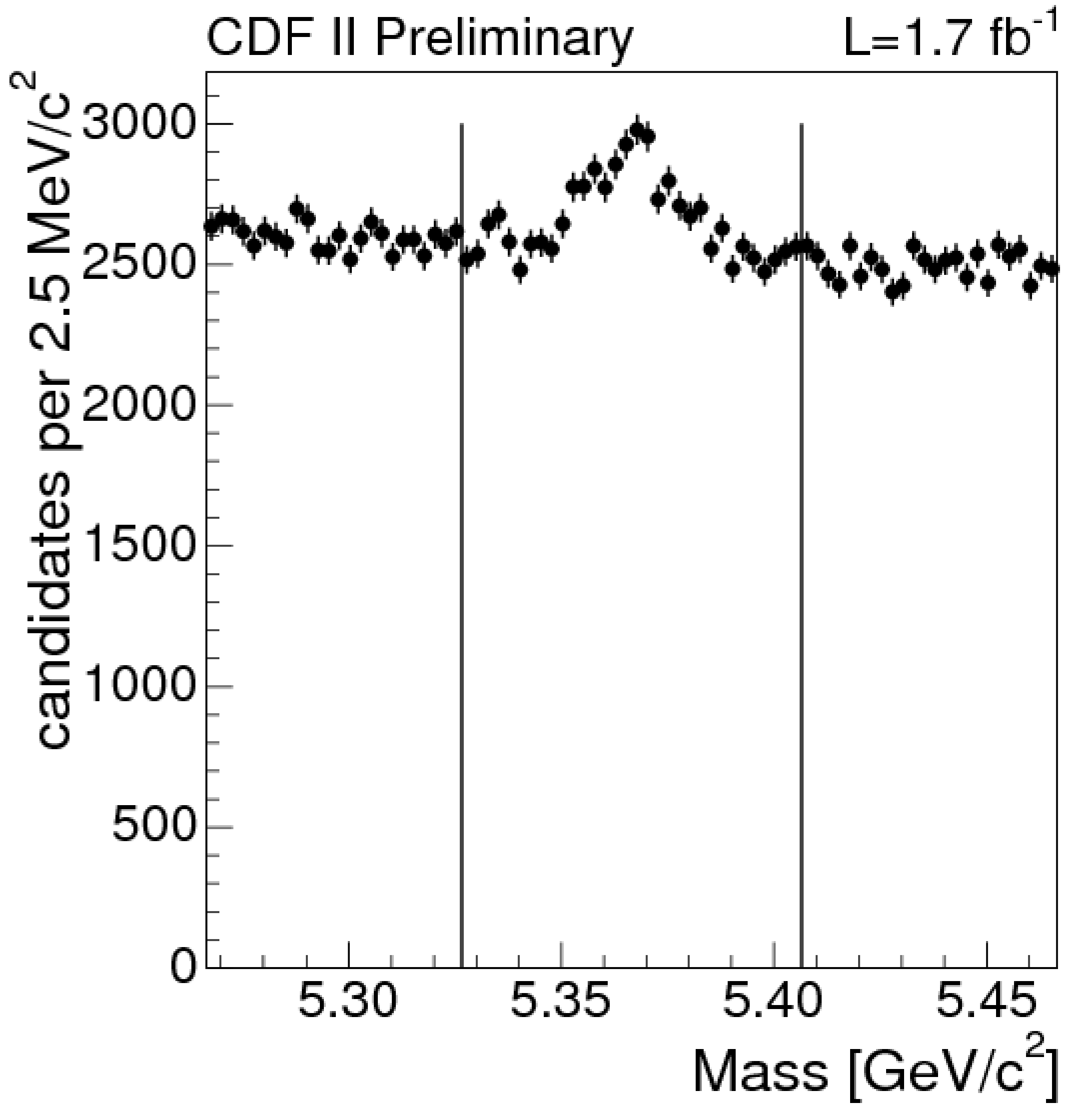
$B_s \to J/\psi\phi$ Selection

Soft kinematic cuts

- Sample dominated by background

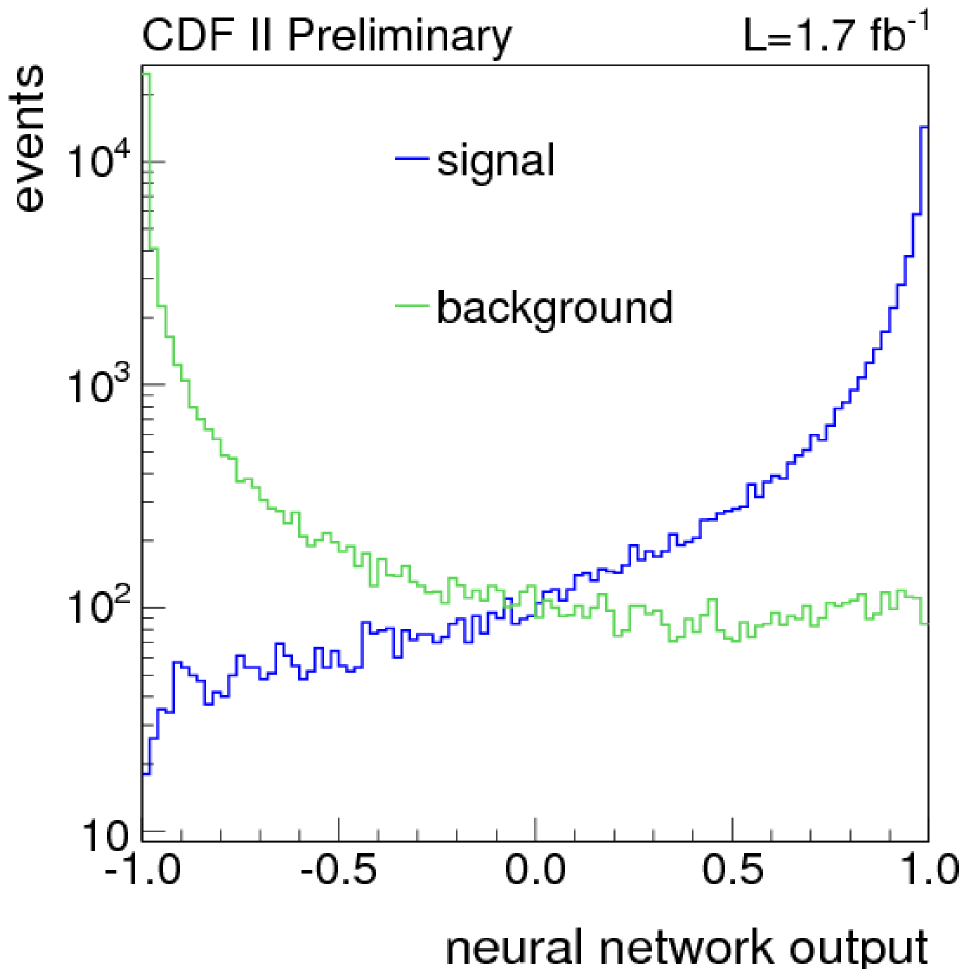
Improve selection with NN

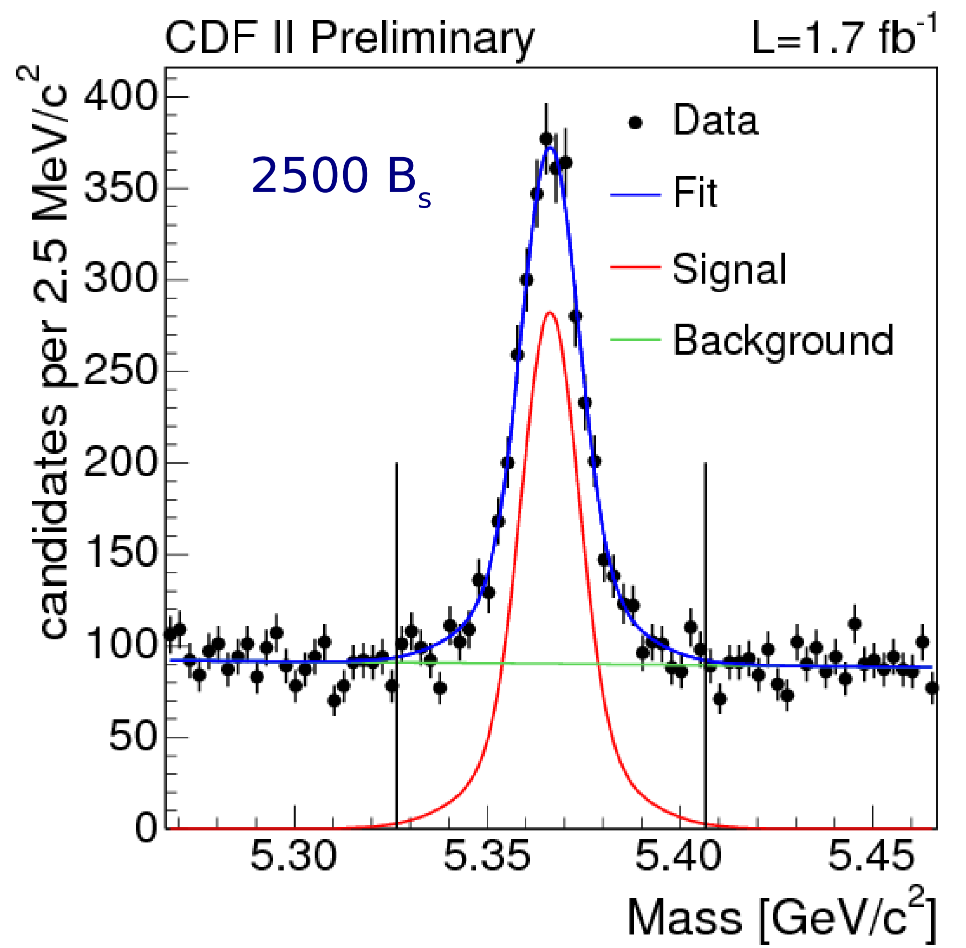
- Kinematic, PID and vertex fit quality variables
- Signal: MC
- Background: data sidebands



Selection Network

Optimize NN cut on signal significance



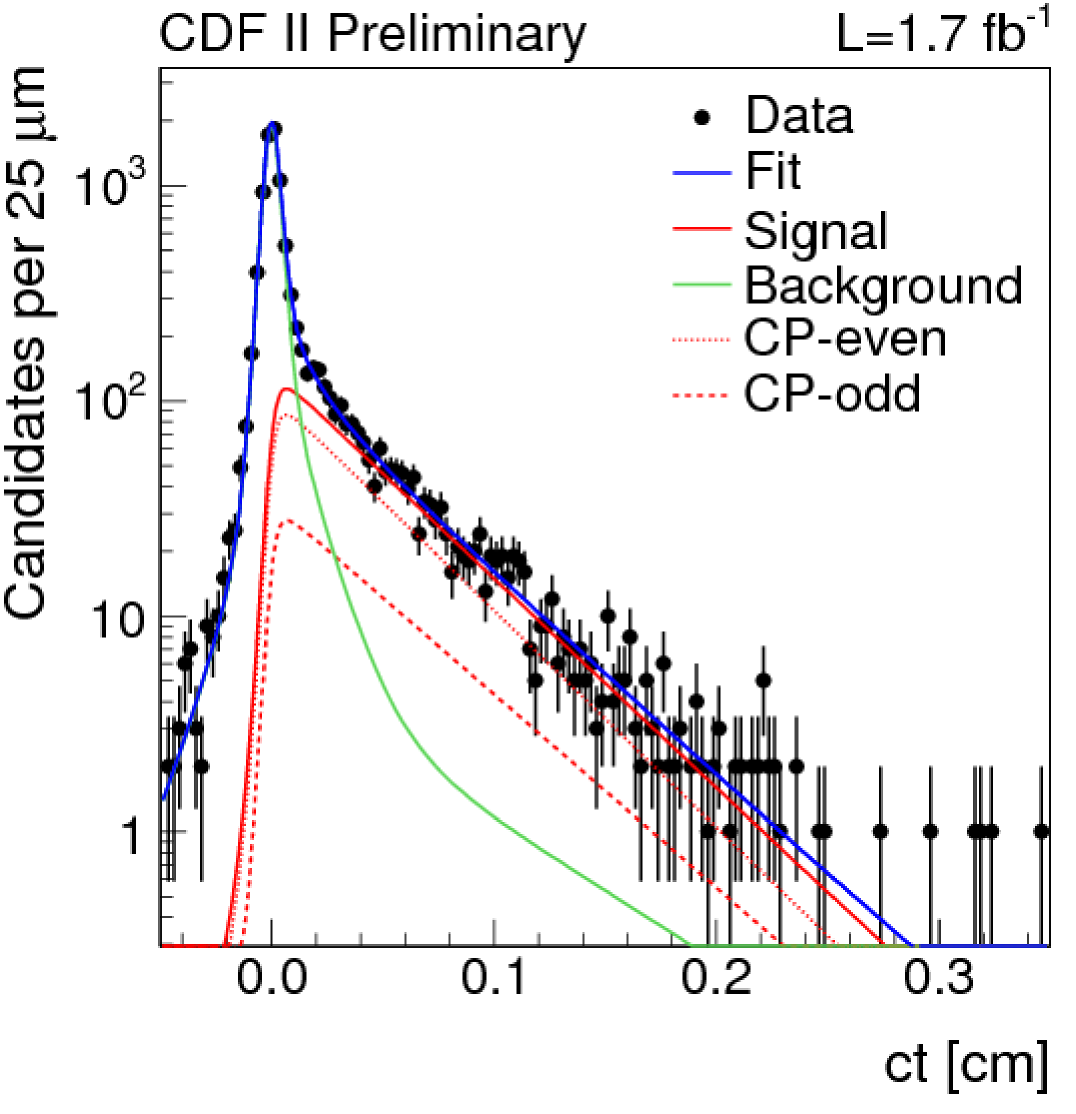


Fit

Maximum likelihood fit in

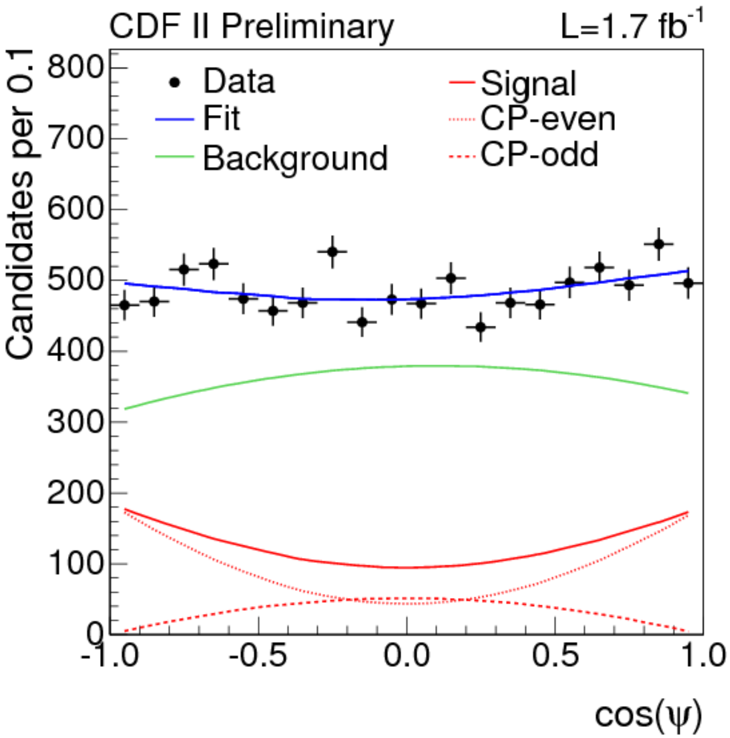
- mass,
- lifetime and
- angular space

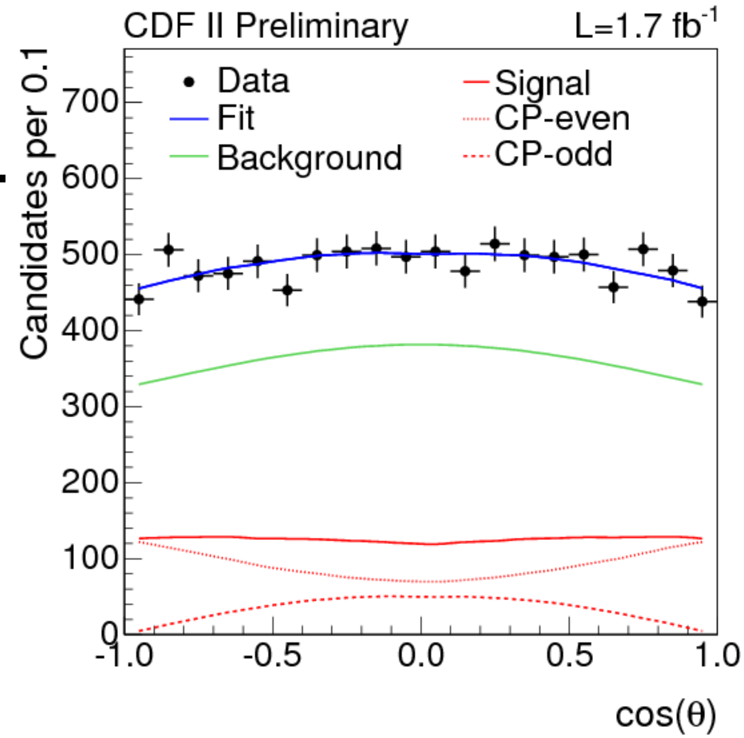
- Differential angular acceptance from MC
- Empirical models for background

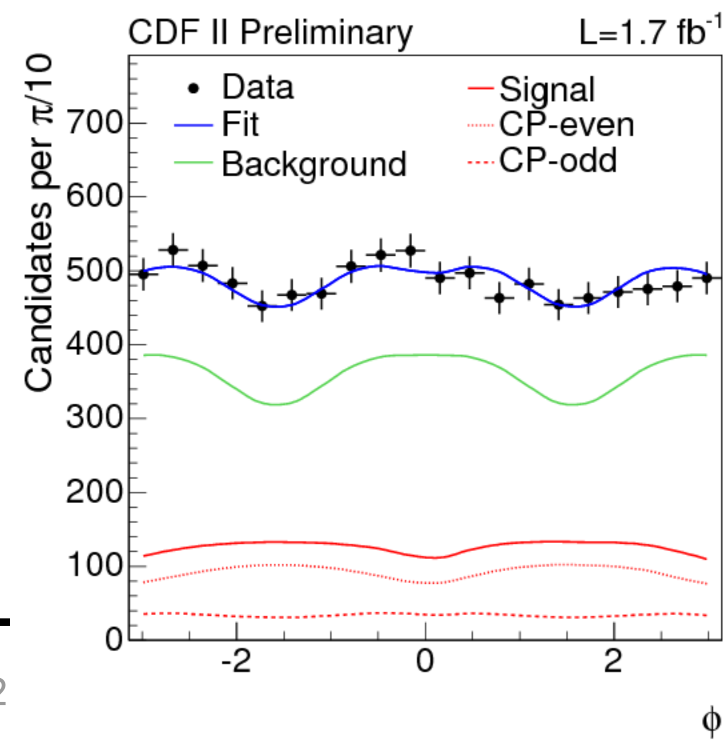


Angular Projections

- Fit describes data well







Result for $\phi_s = 0$

Assuming no CP violation:

- $\Delta\Gamma_s = 0.076\ _{-0.063}^{+0.059}$ (stat) ± 0.006 (syst) ps^{-1}
- $c\tau_s$ = 456 ± 13 (stat) ± 7 (syst) μm
- $|A_0|^2$ = 0.530 ± 0.021(stat) ± 0.007 (syst)
- $|A_{||}|^2$ = 0.230 ± 0.027(stat) ± 0.009 (syst)

$\Delta\Gamma_s$ measurement agrees well with standard model (0.096) and D0 result

Systematic uncertainties:
- Angular background model
- Mass resolution model
- Lifetime resolution model
- B^0 cross feed
- Acceptance description
- Silicon tracker alignment

Constraint on B^0 lifetime ±1%:

- $\Delta\Gamma_s$ = 0.081 ± 0.050 (stat) ± 0.006 (syst) ps^{-1}
- $c\tau_s$ = 458 ± 5 (stat) ± 7 (syst) μm

Allowing for CP violation

Additional parameters:

CP violating phase ϕ_s and strong phase $\delta_\perp$

$$\begin{aligned}\frac{d^4P(\vec{\omega},t)}{d\vec{\omega}dt} \propto\ & |A_0(0)|^2 f_1 \mathcal{T}_+ + |A_{||}(0)|^2 f_2 \mathcal{T}_+ \\ +\ & |A_\perp(0)|^2 f_3 \mathcal{T}_- + |A_0(0)||A_{||}(0)| f_5 \cos(\delta_{||}) \mathcal{T}_+ \\ +\ & |A_{||}(0)||A_\perp(0)| f_4 \cos(\delta_\perp - \delta_{||}) \sin\phi_s (e^{-\Gamma_H t} - e^{-\Gamma_L t})/2 \\ +\ & |A_0(0)||A_\perp(0)| f_6 \cos(\delta_\perp) \sin\phi_s (e^{-\Gamma_H t} - e^{-\Gamma_L t})/2\end{aligned}$$

$$\mathcal{T}_\pm = ((1 \pm \cos\phi_s) e^{-\Gamma_L t} + (1 \mp \cos\phi_s) e^{-\Gamma_H t})/2$$

Invariant under transformations

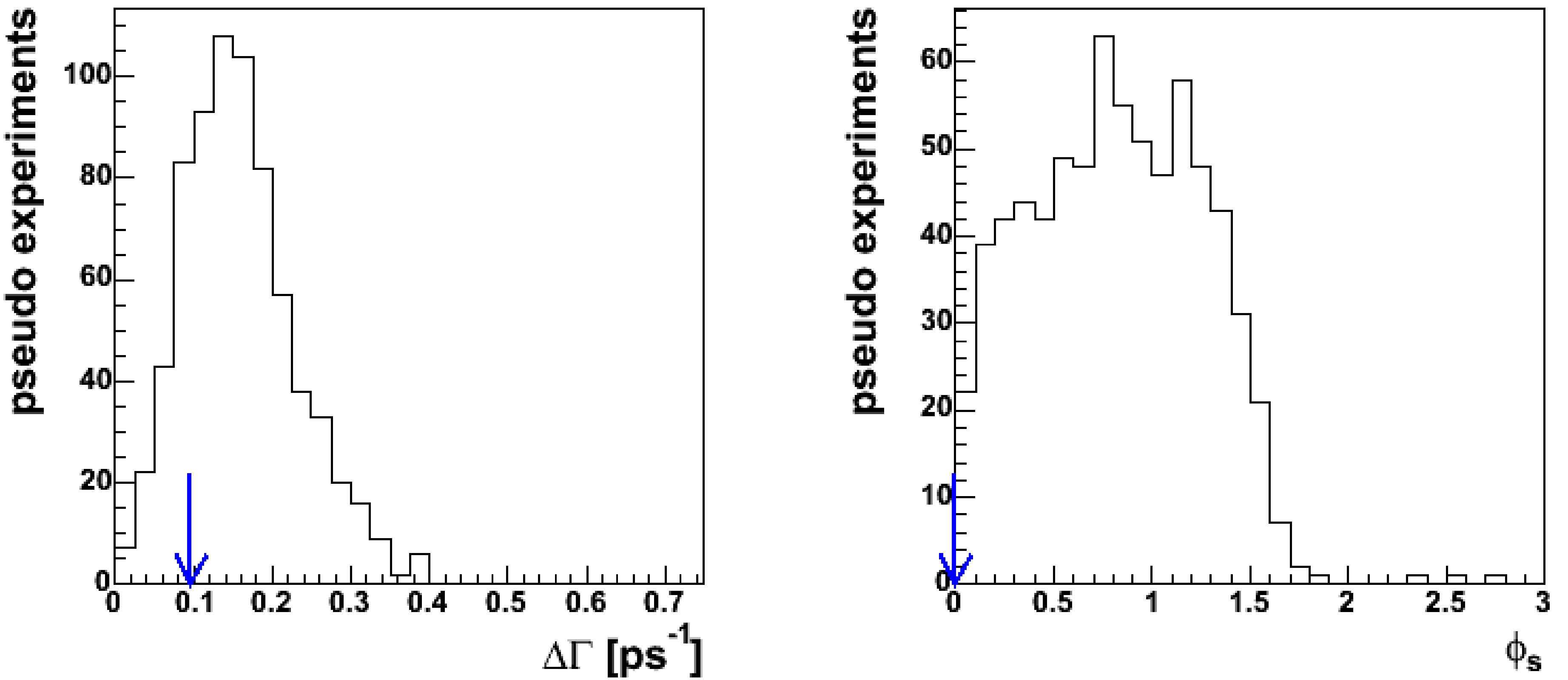
- $\phi_s \rightarrow -\phi_s$, $\delta_\perp \rightarrow \delta_\perp + \pi$
- $\Delta\Gamma \rightarrow -\Delta\Gamma$, $\phi_s \rightarrow \phi_s + \pi$

$\Rightarrow$ 4 fold ambiguity

(quote only solution with ϕ_s>0, $\Delta\Gamma$>0)

Pseudo Experiment Studies

Input: $\Delta\Gamma$ = 0.096, ϕ_s = 0



➔ Biased fit results!

Reason for bias

$$\frac{d^4P(\vec{\omega},t)}{d\vec{\omega}\,dt} \propto |A_0(0)|^2 f_1 \mathcal{T}_+ + |A_{||}(0)|^2 f_2 \mathcal{T}_+$$
$$+ |A_\perp(0)|^2 f_3 \mathcal{T}_- + |A_0(0)||A_{||}(0)| f_5 \cos(\delta_{||}) \mathcal{T}_+$$
$$+ |A_{||}(0)||A_\perp(0)| f_4 \cos(\delta_\perp - \delta_{||}) \sin\phi_s (e^{-\Gamma_H t} - e^{-\Gamma_L t})/2$$
$$+ |A_0(0)||A_\perp(0)| f_6 \cos(\delta_\perp) \sin\phi_s (e^{-\Gamma_H t} - e^{-\Gamma_L t})/2$$

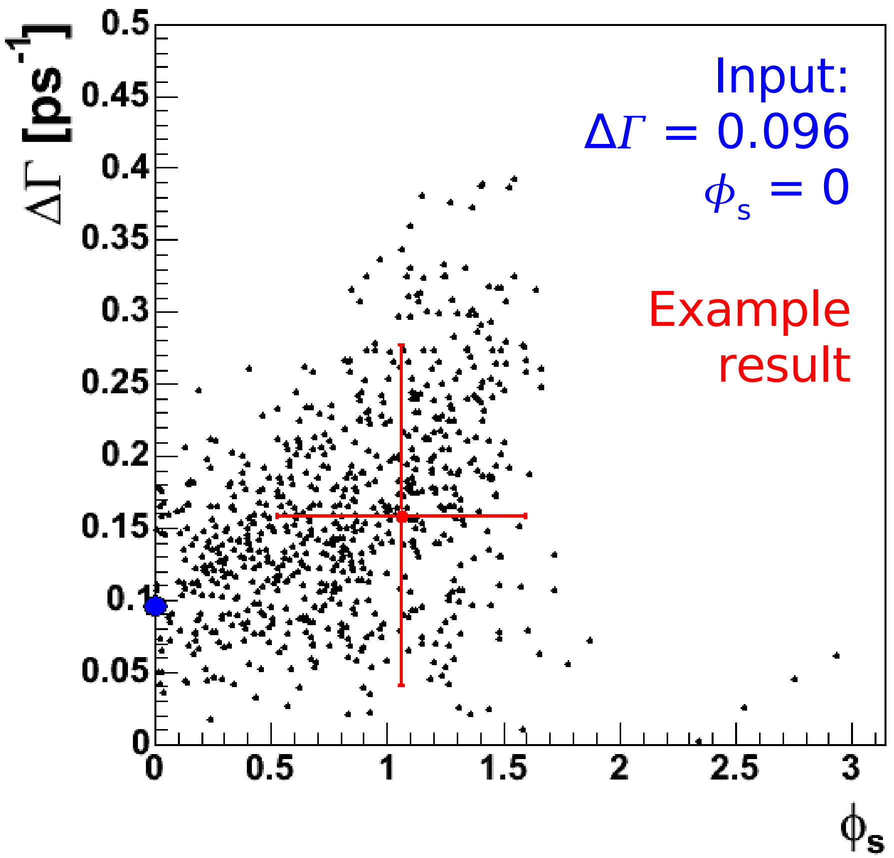
$$\mathcal{T}_\pm = ((1 \pm \cos\phi_s) e^{-\Gamma_L t} + (1 \mp \cos\phi_s) e^{-\Gamma_H t})/2$$

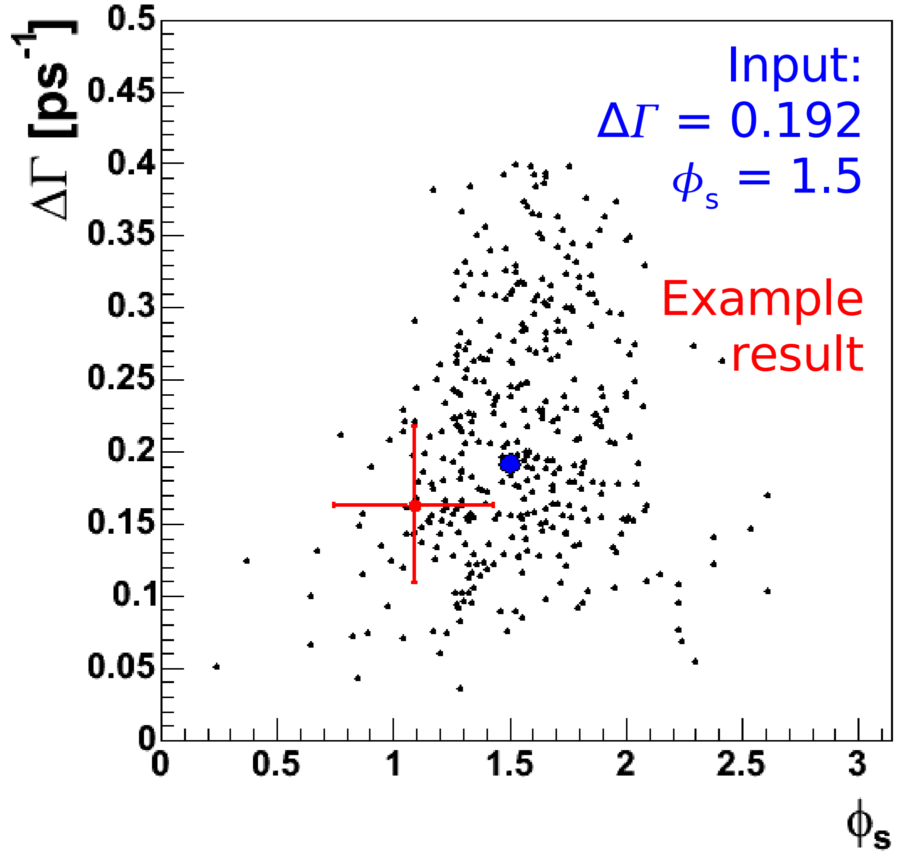
For $\phi_s = 0$: $\delta_\perp$ undetermined

For $\Delta\Gamma = 0$: ϕ_s and $\delta_\perp$ undetermined

- Reduced degrees of freedom for $\phi_s \to 0$ and $\Delta\Gamma \to 0$
- Bias away from $\phi_s = 0$ and $\Delta\Gamma = 0$

Pseudo Experiments Example





Point estimate is biased

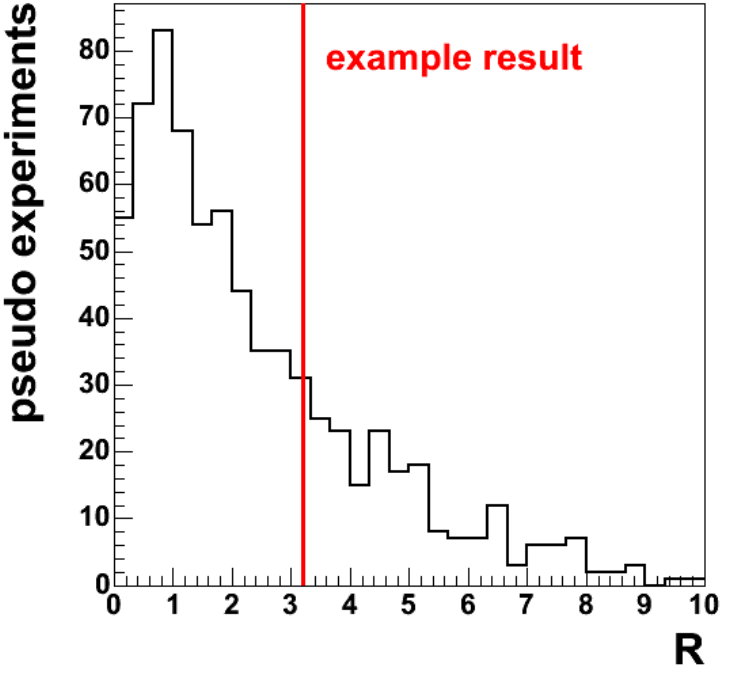
- Quote p-value and confidence region instead

P-Value Calculation

- Quantify agreement of measurement with given true values of $\Delta\Gamma$ and ϕ_s

- Likelihood ratio (Feldman-Cousins):

$$R(\Delta\Gamma, \phi_s) = -\ln \frac{\mathcal{L}(\Delta\Gamma, \phi_s, \theta'_{fit})}{\mathcal{L}(\Delta\Gamma_{fit}, \phi_{s,fit}, \theta_{fit})}$$



- p-value = fraction with R > R_{data}

- Confidence region: $\Delta\Gamma$ and ϕ_s points with p-value > 1 - C.L.

Data plot in progress...

Conclusions

Assuming no CP violation:

- Measurement of lifetime difference in $B_s \to J/\psi\phi$ decays:
  - $\Delta\Gamma_s = 0.076\,_{-0.063}^{+0.059}$ (stat) ± 0.006 (syst) ps^{-1}
  - $c\tau_s$ = 456 ± 13 (stat) ± 7 (syst) μm

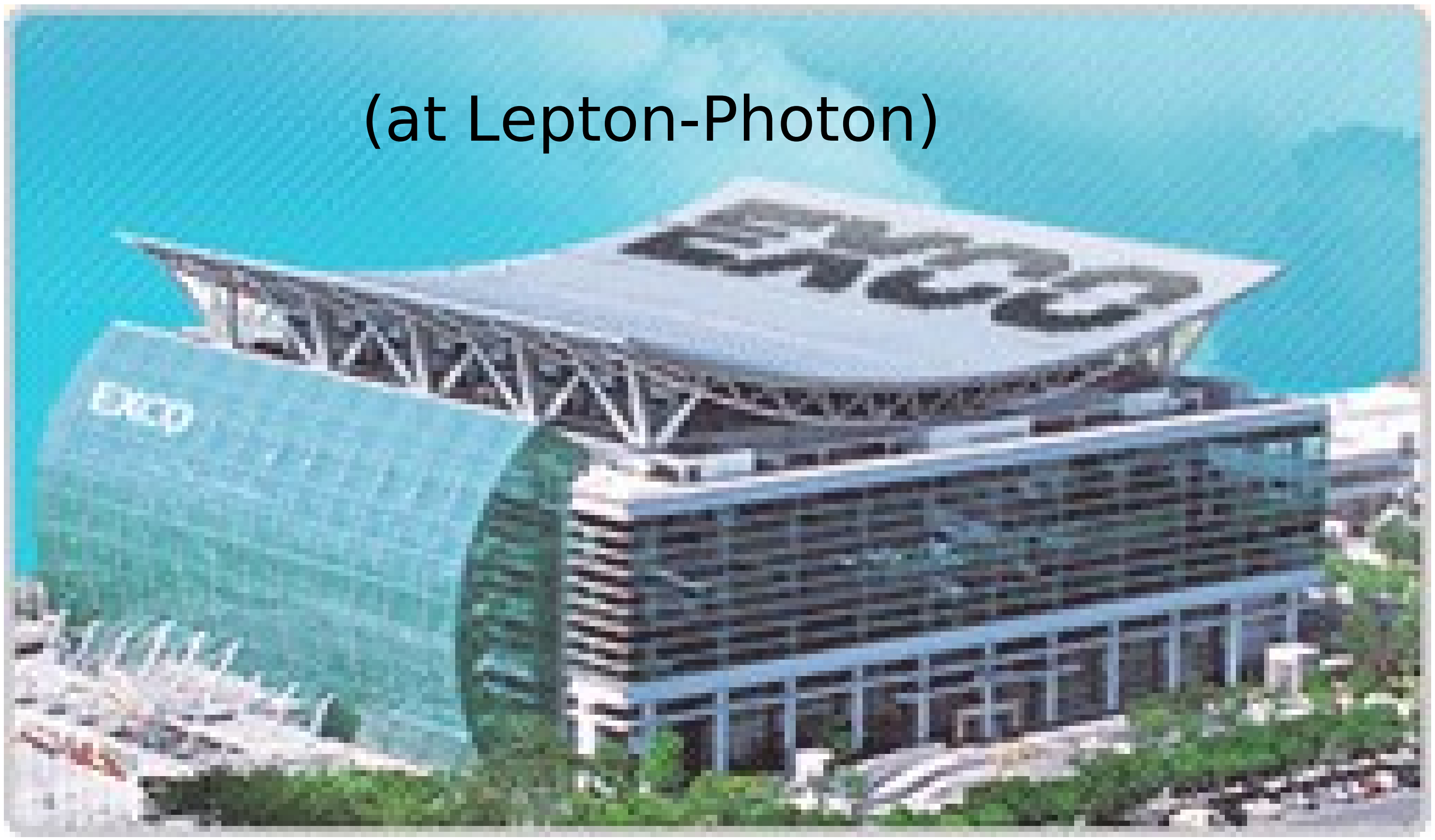
Allowing for CP violation:

- Maximum likelihood fit with CP violating phase ϕ_s is biased
- Bias reduces sensitivity to new physics
- Will present confidence region instead of point estimate

Outlook

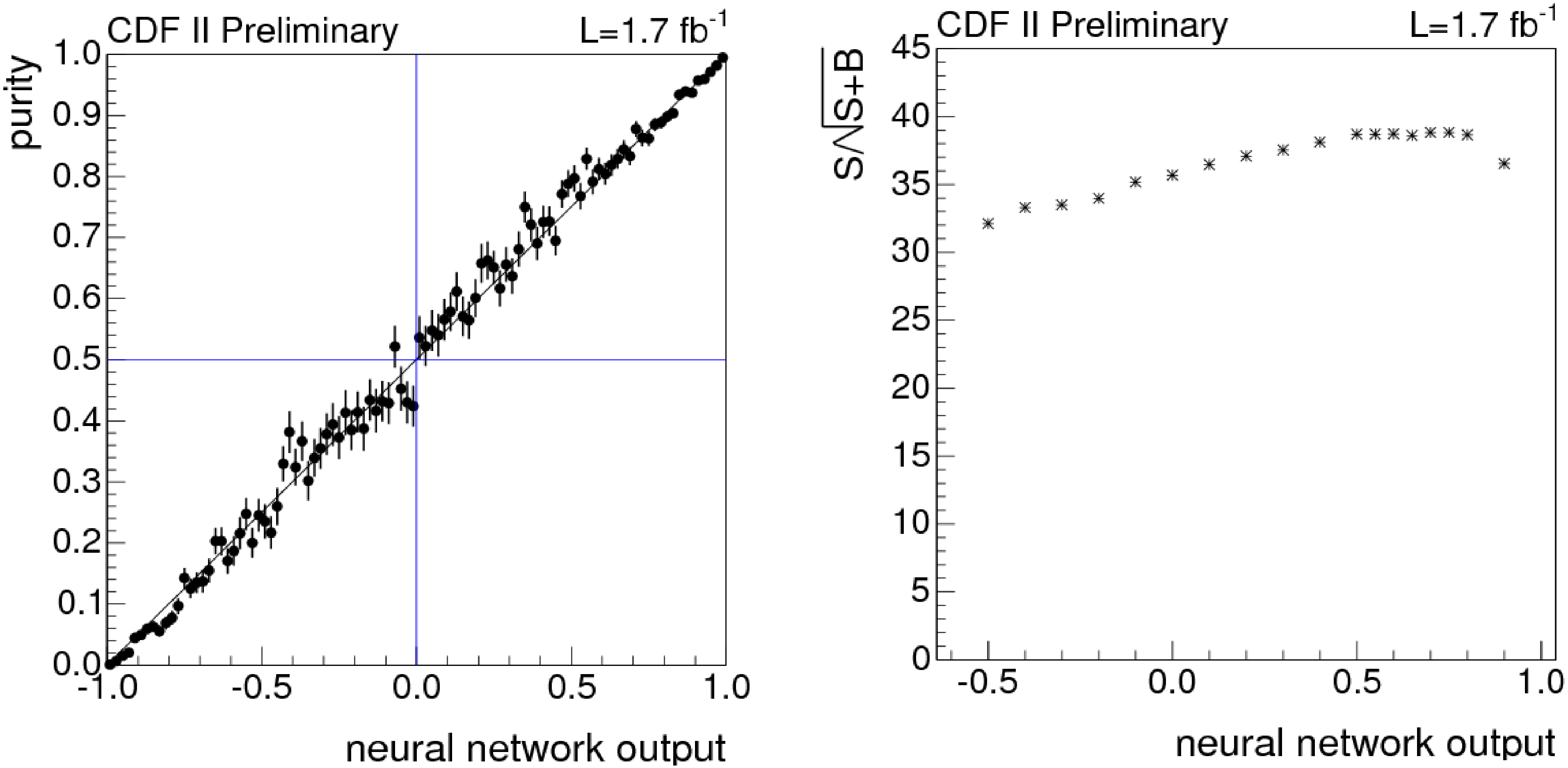
to be continued

(at Lepton-Photon)



Backup

Selection Neural Network



Likelihood Scans